US 20200309112A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2020/0309112 A1
Yakimchuk et al.
(43) Pub. Date: Oct. 1, 2020

(54) PUMPING UNIT HAVING ZERO-IMBALANCED BEAM, LAGGING COUNTERWEIGHTS, AND SETBACK CRANK POINT

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(21) Appl. No.: **16/372,218**

(22) Filed: **Apr. 1, 2019**

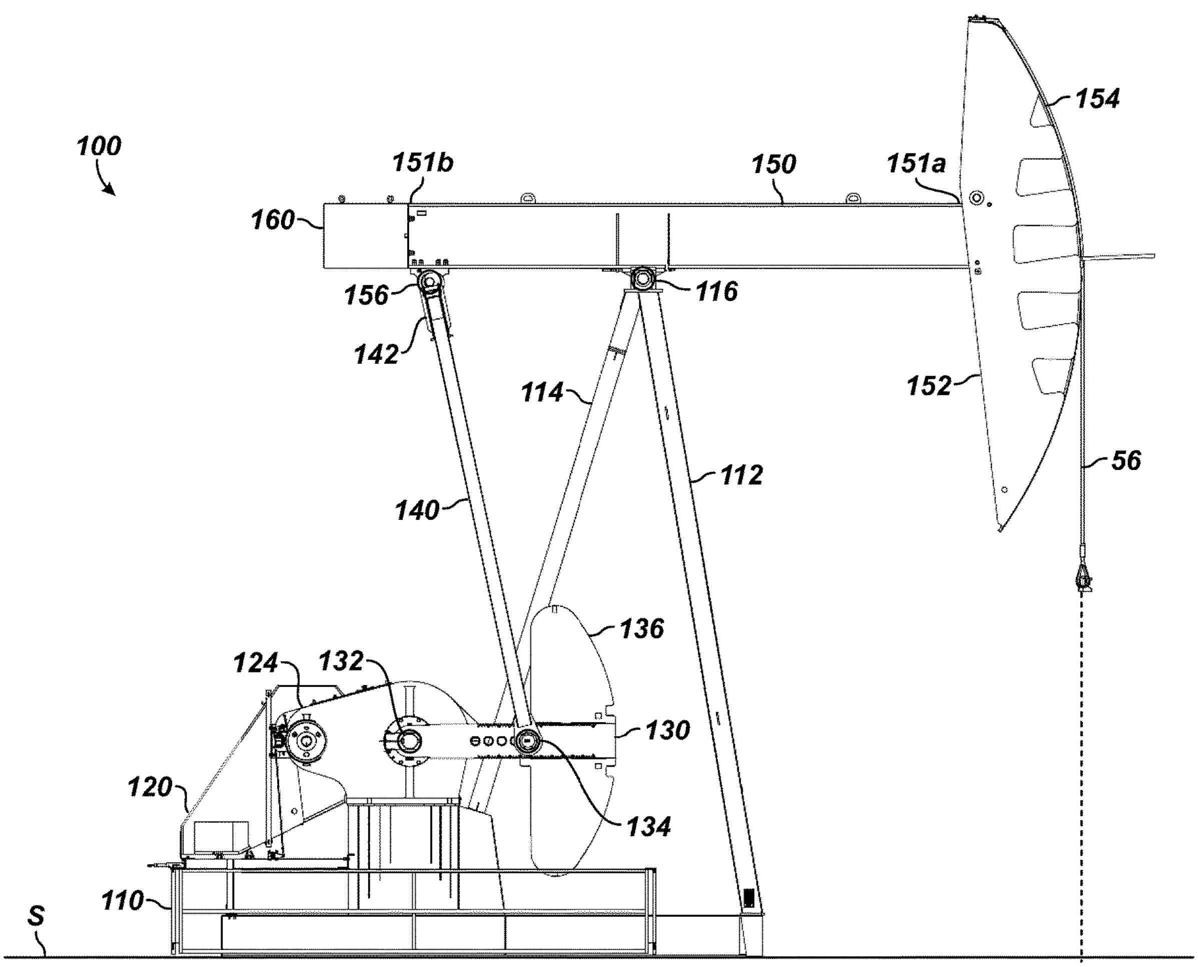
Publication Classification

(51) Int. Cl.
F04B 47/02 (2006.01)
E21B 43/12 (2006.01)

(52) U.S. Cl.
CPC *F04B 47/022* (2013.01); *E21B 43/127* (2013.01); *F04B 47/028* (2013.01)

(57) ABSTRACT

A surface unit can operate as a longer stroke unit to reciprocate a rod string for a downhole pump in a well. The unit has an end weight that gives the walking beam and head a zero-imbalance about the unit's fulcrum point. The unit can also operate as a phased unit in which the counterweights of the crank arms lag behind the pivot connection and/or the crank point is disposed rearward of the equalizer bearing of the walking beam.



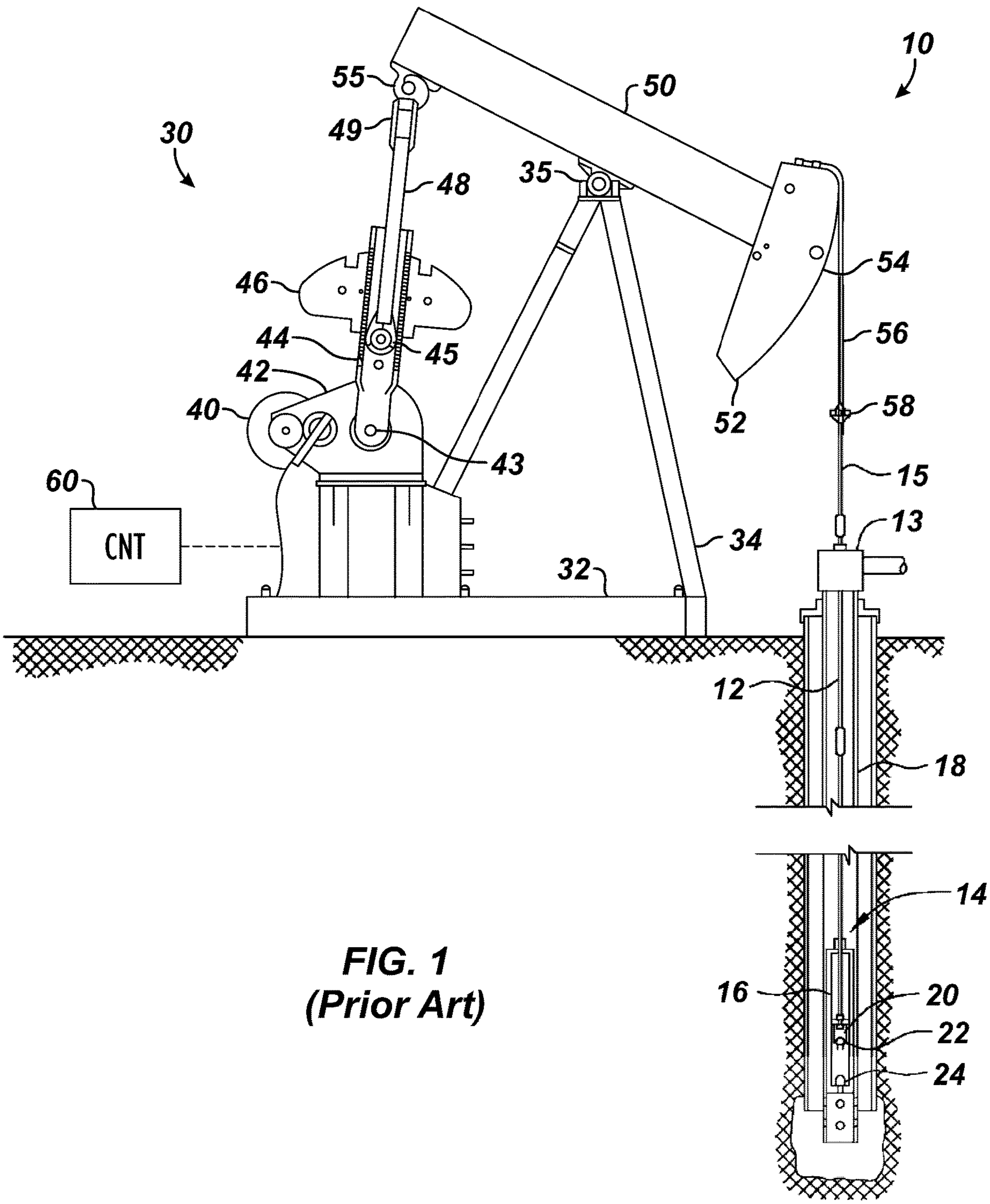


FIG. 1
(Prior Art)

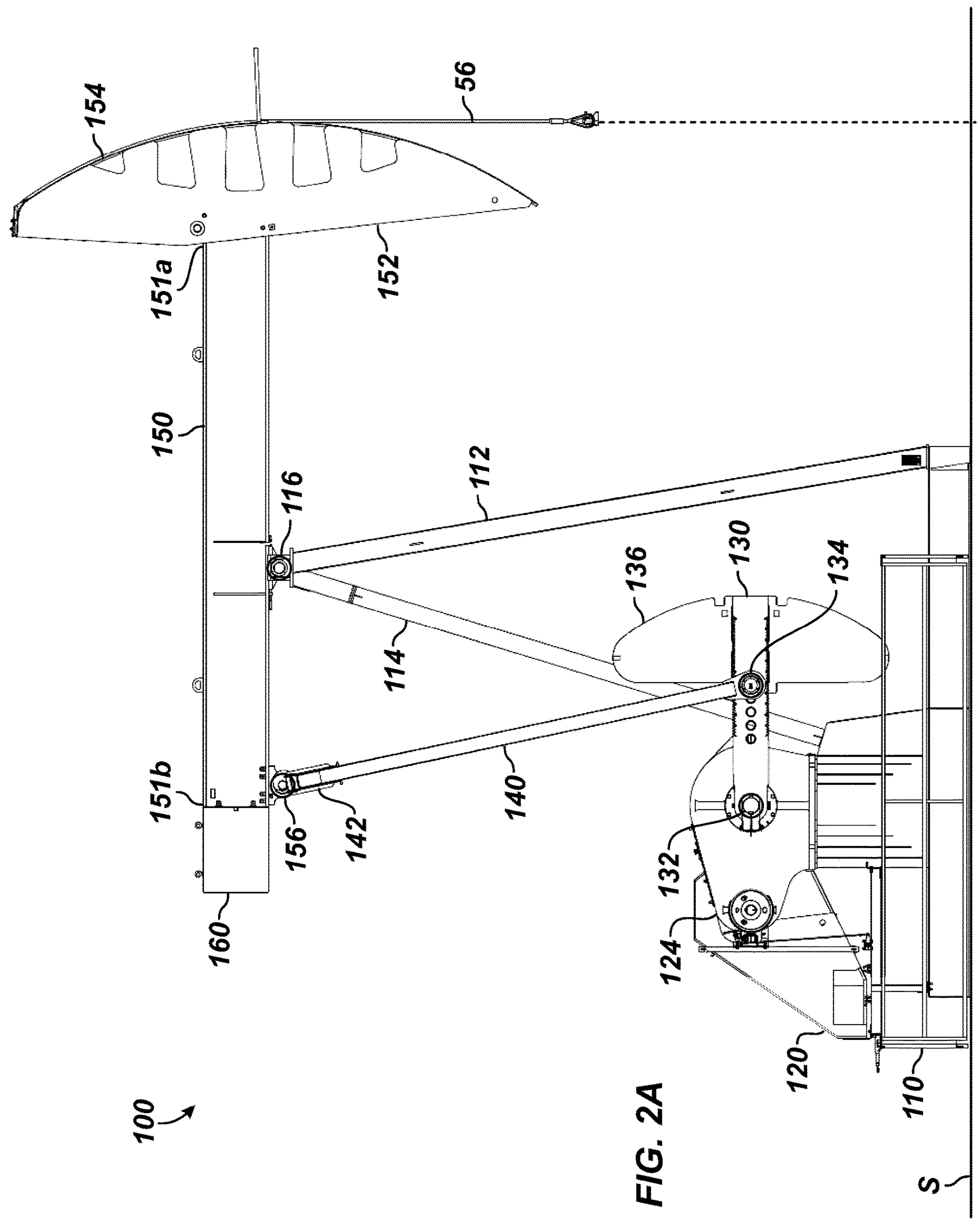
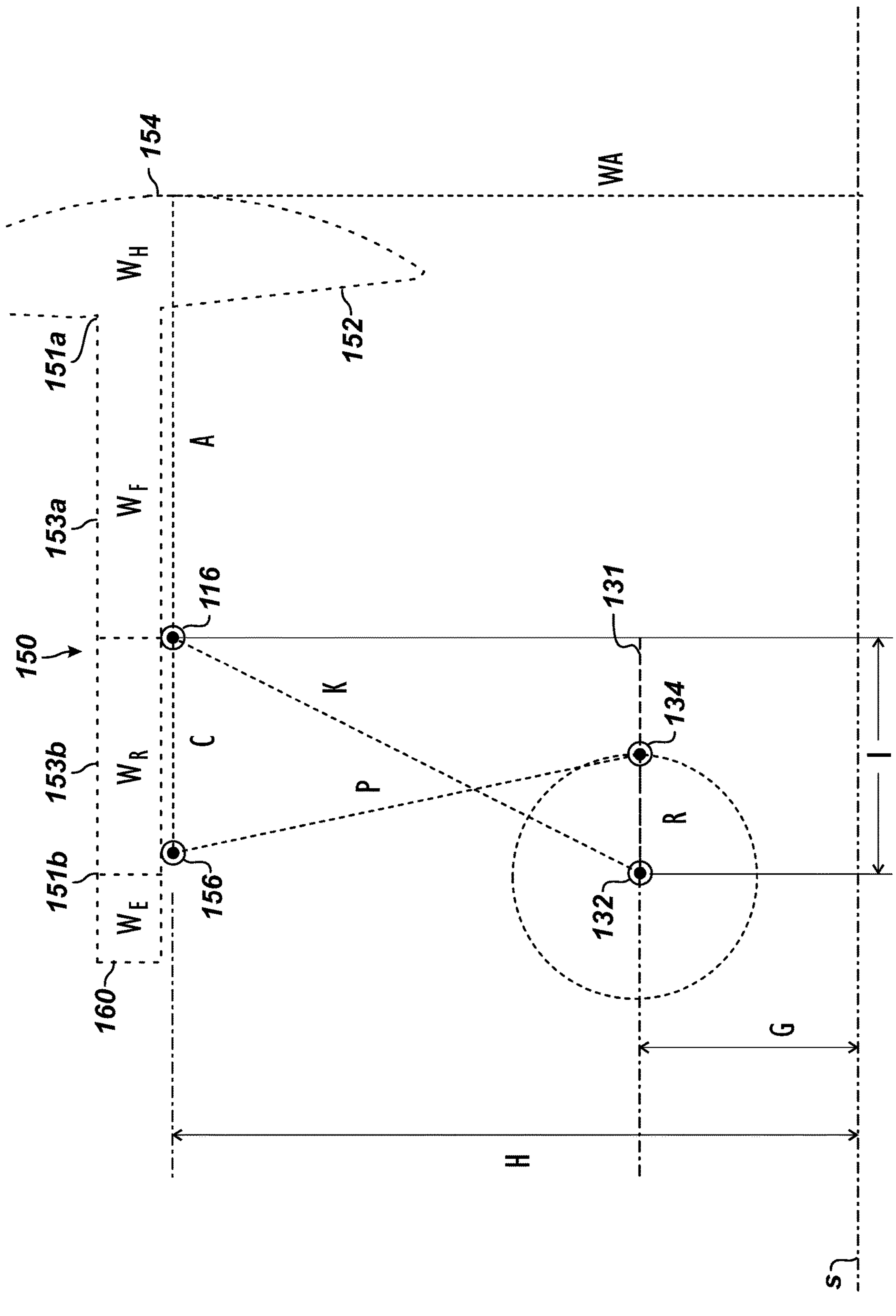

100
154
56
151a
152
150
116
112
136
130
134
114
151b
140
156
142
132
160
124
120
110
S

FIG. 2A


154
WA
W_H
152
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A
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116
131
150
K
C
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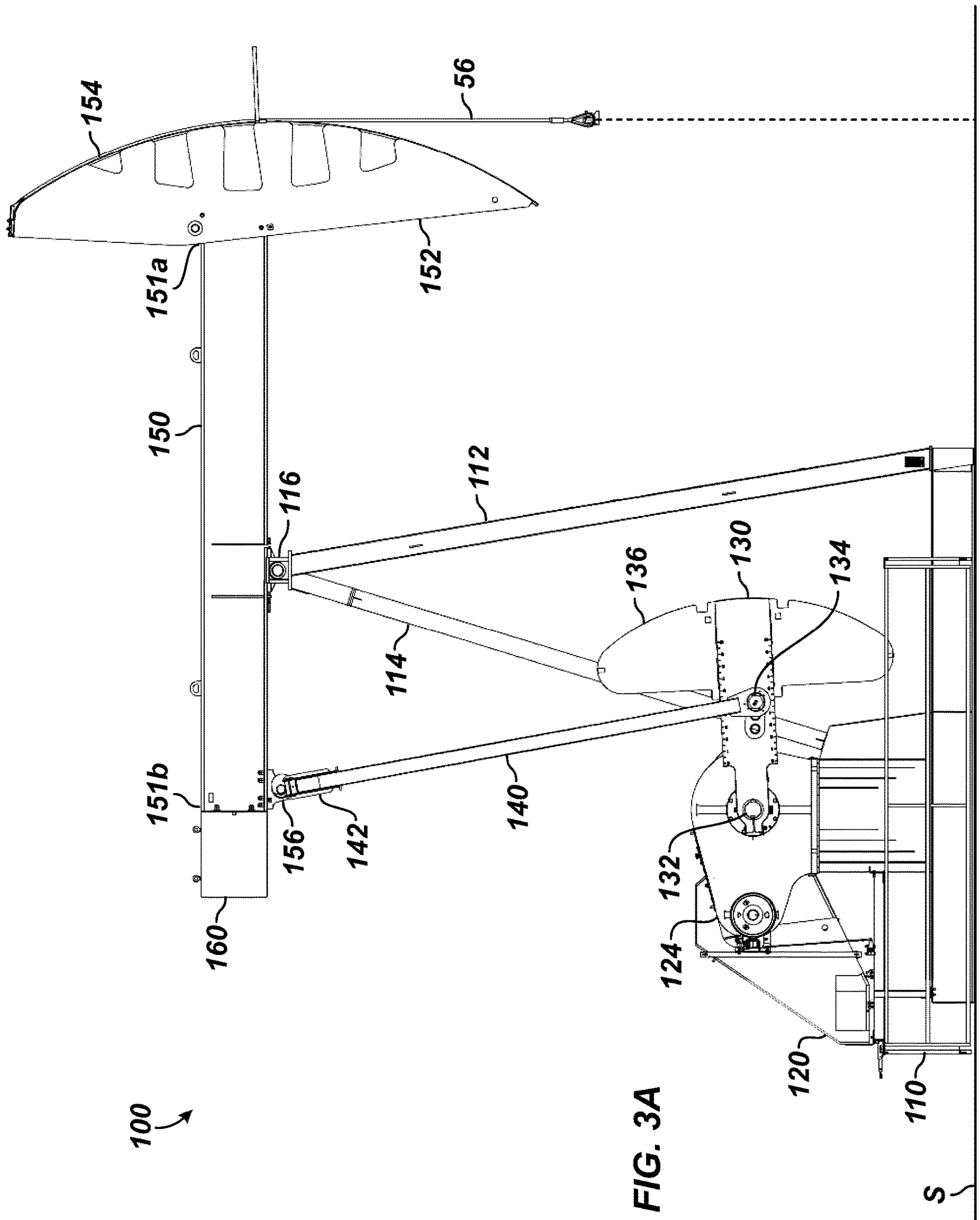
FIG. 2B


100
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56
151a
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151b
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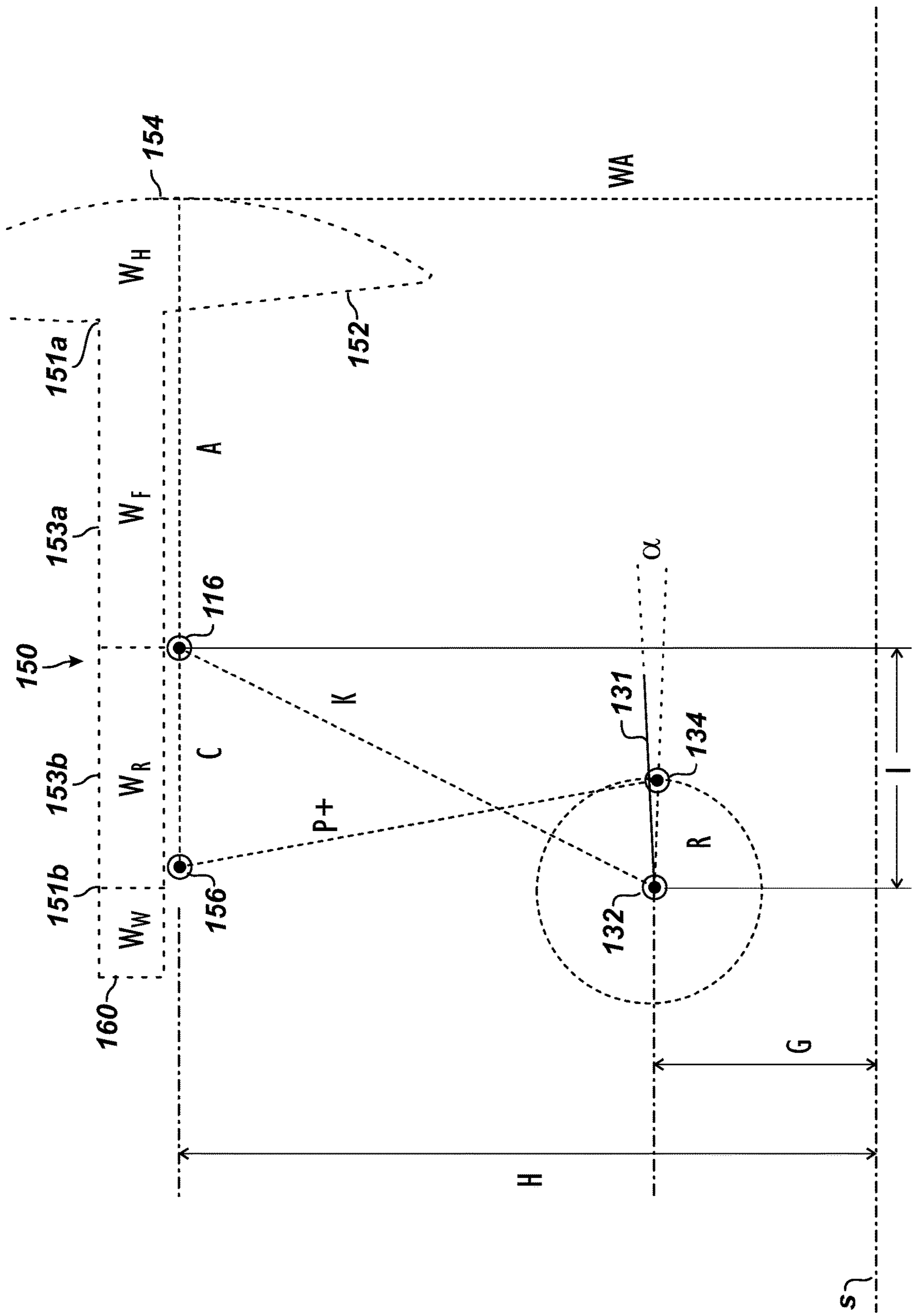
120
110
S

FIG. 3A


154
WA
W_H
152
151a
A
W_F
153a
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116
150
K
131
134
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151b
156
W_W
132
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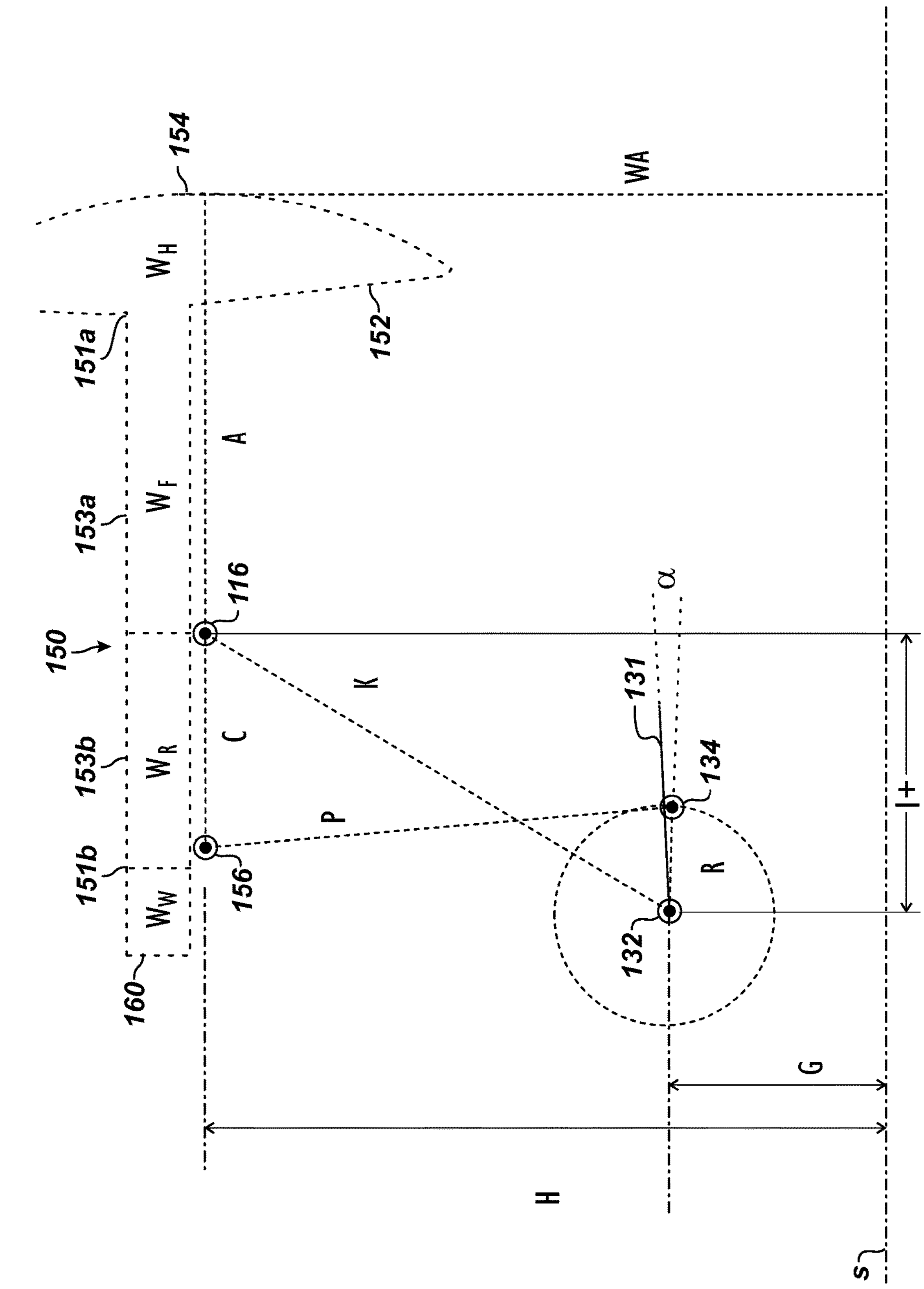
FIG. 3B


154
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132
160
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FIG. 3C

PUMPING UNIT HAVING ZERO-IMBALANCED BEAM, LAGGING COUNTERWEIGHTS, AND SETBACK CRANK POINT

BACKGROUND OF THE DISCLOSURE

[0001] Reciprocating pump systems, such as sucker rod pump systems, extract fluids from a well and employ a downhole pump connected to a driving source at the surface. A rod string connects the surface driving force to the downhole pump in the well. When operated, the driving source cyclically raises and lowers the downhole pump, and with each stroke, the downhole pump lifts well fluids toward the surface.

[0002] For example, FIG. **1** shows a sucker rod pump system **10** used to produce fluid from a well. A downhole pump **14** has a barrel **16** with a standing valve **24** located at the bottom. The standing valve **24** allows fluid to enter from the wellbore, but does not allow the fluid to leave. Inside the pump barrel **16**, a plunger **20** has a traveling valve **22** located at the top. The traveling valve **22** allows fluid to move from below the plunger **20** to the production tubing **18** above, but does not allow fluid to return from the tubing **18** to the pump barrel **16** below the plunger **20**. A driving source (e.g., a pump jack or pumping unit **30**) at the surface connects by a rod string **12** to the plunger **20** and moves the plunger **20** up and down cyclically in upstrokes and downstrokes.

[0003] During the upstroke, the traveling valve **22** is closed, and any fluid above the plunger **20** in the production tubing **18** is lifted towards the surface. Meanwhile, the standing valve **24** opens and allows fluid to enter the pump barrel **16** from the wellbore.

[0004] At the top of stroke, the standing valve **24** closes and holds in the fluid that has entered the pump barrel **16**. Furthermore, throughout the upstroke, the weight of the fluid in the production tubing **18** is supported by the traveling valve **22** in the plunger **20** and, therefore, also by the rod string **12**, which causes the rod string **12** to stretch. During the downstroke, the traveling valve opens, which results in a rapid decrease in the load on the rod string **12**. The movement of the plunger **20** from a transfer point to the bottom of stroke is known as the "fluid stroke" and is a measure of the amount of fluid lifted by the pump **14** on each stroke.

[0005] At the surface, the pump jack **30** is driven by a prime mover **40**, such as an electric motor or internal combustion engine, mounted on a pedestal above a base **32**. Typically, a pump controller **60** monitors, controls, and records the pump unit's operation. Structurally, a Samson post **34** on the base **32** provides a fulcrum on which a walking beam **50** is pivotally supported by a saddle bearing assembly **35**.

[0006] Output from the motor **40** is transmitted to a gearbox **42**, which provides low-speed, high-torque rotation of a crankshaft **43**. Both ends of the crankshaft **43** rotate crank arms **44** having counterbalance weights **46**. Each crank arm **44** is pivotally connected to a pitman arm **48** by a crank pin bearing **45**. In turn, the two pitman arms **48** are connected to an equalizer bar **49**, which is pivotally connected to the rear end of the walking beam **50** by an equalizer bearing assembly **55**.

[0007] A horsehead **52** with an arcuate forward face **54** is mounted to the forward end of the walking beam **50**. As is typical, the face **54** may have tracks or grooves for carrying a flexible wire rope bridle **56**. At its lower end, the bridle **56** terminates with a carrier bar **58**, upon which a polished rod **15** is suspended. The polished rod **15** extends through a packing gland or stuffing box at the wellhead **13**. The rod string **12** of sucker rods hangs from the polished rod **15** within the tubing string **18** located within the well casing and extends to the downhole pump **14**.

[0008] As is known, pump jack operating characteristics are typically characterized by the American Petroleum Institute ("API") Specifications, which expresses parameters as a function of the geometry of a pumping unit's four-bar linkage. Standardized API linkage geometry designates: dimension "A" as the distance from the center of the saddle bearing **35** to the centerline of the polished rod **15**; dimension "C" as the distance from the center of the saddle bearing **35** to the center of the equalizer bearing **55**; dimension "P" as the effective length of the pitman arm **48** as measured from the center of the equalizer bearing **55** to the center of the crank pin bearing **45**; dimension "R" as the distance from the centerline **43** of the crankshaft to the center of the crank pin bearing **45**; dimension "H" as the height from the center of the saddle bearing **35** to the bottom of the pump jack base **32**; dimension "I" is the horizontal distance from the center of the saddle bearing **25** to the centerline **43** of the crankshaft; dimension "G" as the height from the centerline **43** of the crankshaft to the bottom of the pump jack base **32**; and dimension "K" as the distance from the centerline **43** of the crankshaft to the center of the saddle bearing **35**. Dimension "K" may be computed as:

$$K=\sqrt{(H-G)^2+I^2}$$

[0009] Alteration of the four-bar linkage may have a significant effect on the operating characteristics of the pumping unit **30**, such as changing the allowable polished rod load, changing the shape of the permissible load envelope, altering the length of the pumping stroke, inducing a phase angle shift in the counterbalance, etc. Moreover, the change in operating characteristics at surface may further affect controls, analysis, and diagnostics of the downhole rod pump because calculations for these features are typically based on the standard four-bar linkage (K-R-P-C).

[0010] A conventional rod pumping unit **10** as in FIG. **1** has considerable inertia effects inherent to the design. The crank arms **42** connected to the gear reducer **42** and having the counterweights **46** affixed to them must overcome the equivalent torque that is applied by the connected rod string **12** extending from the wellbore to the horsehead **52**. These counterweights **46** are significantly large masses (~1,800 lb. for a mid-range counterweight) so a considerable amount of torque from the prime mover **40** is needed to initiate their rotational motion. Additionally, the balance beam **50** and associated parts that convert the rotary motion of the crank arms **42** into articulating motion also have significant mass that also require torque from the prime mover **40** to sustain the desired rocking motion that lifts and lowers the rod string **12**. Even though the conventional rod pumping unit **10** has been in use for over 80 years, some of the inertia effects of both the rotational and articulating elements are not as well-known as some might believe.

[0011] There are some pumping unit designs that are different than the conventional pumping unit **10** of FIG. **1**. For example, it has been known for some time in the art to place weight at the rearward end of a walking beam for a surface pumping unit. As two examples, U.S. Pat. Nos.

2,175,588 and 2,408,200 have additional weight on the rearward end of the walking beam. The rearward end of the beam extends a considerable distance beyond the point of attachment of the pitman arms and is provided with a weight for counterbalancing the pumping loads.

[0012] Another type of pumping unit having a weight on the rearward end of the beam is a beam balanced unit. As opposed to a crank balanced unit as in FIG. **1**, this type of beam balanced unit does not use counterweights on crank arms. Instead, the beam balanced unit only uses counterweight on the rearward end of the beam. Typically, the weight is adjustable so operators can determine the proper number or placement of weight to achieve the desired counterbalance. Such a beam balance unit has been used for low production installations, such as for producing a shallow well in a mature oilfield.

[0013] A curved beam pumping unit available from Schlumberger uses an adjustable weight positioned on the bent beam's rearward end. The conventional crank weight and the adjustable beam weight on the curved beam are intended to benefit the gearbox torque of this curved beam pumping unit.

[0014] The subject matter of the present disclosure is directed to overcoming, or at least reducing the effects of, one or more of the problems set forth above.

SUMMARY OF THE DISCLOSURE

[0015] According to one arrangement of the present disclosure, a surface pumping unit is operated by a prime mover for reciprocating a rod load for a downhole pump in a well. The unit comprises a frame, a beam, a crank arm, a counterweight, and a pitman art.

[0016] The frame is disposed at surface and has a fulcrum point. The beam is pivotable at the fulcrum point of the frame. The beam has a first end having a head connecting to the rod load extending from the well. The beam has a second end having a first bearing point. An end weight is disposed on the second end of the beam rearward of the first bearing point. A forward section of the first end of the beam and the head disposed forward of the fulcrum point has a forward weight. A rearward section of the second end of the beam and the end weight disposed rearward of the fulcrum point having a rearward weight. The forward weight is balanced relative to the rearward weight.

[0017] The crank arm is connected to the prime mover and is rotatable thereby about a crank point. The counterweight is disposed on the crankarm, and the pitman arm is connected between the first bearing point on the beam and a second bearing point on the crank arm. The second bearing point is disposed between the counterweight and the crank point.

[0018] The crank arm rotated by the prime mover about the crank point translates the pitman arm to oscillate the beam on the fulcrum point and reciprocates the rod load along the wellbore axis.

[0019] The frame can include: a base disposed at the surface; and a post extending from the base to the fulcrum point along a line from vertical.

[0020] The beam can define a straight axis having first and second sections. The first section from the fulcrum point to a face of the head can have a first length (A), and the second section from the fulcrum point to the first bearing point can have a second length (C). The first length (A) can be greater than the second length (C).

[0021] The fulcrum point can comprise a saddle bearing, the first bearing point can comprise an equalizer bearing, and the second bearing point can comprise a crank pin bearing. The unit can include another crank arm connected to the prime mover and rotatable thereby about another crank point; and another pitman arm connected between another first bearing point on the beam and another second bearing point on the other crank arm, wherein the pitman arms connect with an equalizer beam at the first bearing point. The unit can further comprise a gear reducer operably connecting the crank point to the prime mover.

[0022] In one configuration, the crank point can be centered vertically below the first bearing point on the beam when the beam is situated horizontally. For instance, the first bearing point can be disposed at a first horizontal dimension (C) along the beam relative to the fulcrum point, and the crank point can be disposed at a second horizontal dimension (I) relative to the fulcrum point. In this configuration, the second horizontal dimension (I) can be approximately equal to the first horizontal dimension (C).

[0023] For this configuration, the second bearing point can be disposed along a longitudinal axis defined by the crank arm. Alternatively, the second bearing point can be disposed offset at an angle from the longitudinal axis of the crank arm.

[0024] In another configuration, the crank point can be situated vertically rearward below the first bearing point on the beam when the beam is situated horizontally. For instance, the first bearing point can be disposed at a first horizontal dimension (C) along the beam relative to the fulcrum point, and the crank point can be disposed at a second horizontal dimension (I) relative to the fulcrum point. The second horizontal dimension (I) can be greater than the first horizontal dimension (C).

[0025] For this other configuration, the second bearing point can be disposed along a longitudinal axis defined by the crank arm. Alternatively, the second bearing point can be disposed offset at an angle from the longitudinal axis of the crank arm.

[0026] According to another arrangement of the present disclosure, a surface pumping unit is operated by a prime mover for reciprocating a rod load for a downhole pump in a well. The unit comprises a frame, a beam, a crank arm, a counterweight, and a pitman arm. The frame is disposed at the surface and has a fulcrum point. The beam is pivotable at the fulcrum point of the frame. A first end of the beam has a head connecting to the rod load extending from the well. A second end of the beam has a first bearing point and has an end weight disposed rearward of the first bearing point.

[0027] The crank arm is connected to the prime mover and is rotatable thereby about a crank point. The counterweight is disposed on the crankarm. The pitman arm is connected between the first bearing point on the beam and a second bearing point on the crank arm. The second bearing point is disposed between the counterweight and the crank point and is disposed offset at an angle from a longitudinal axis defined by the crank arm.

[0028] A forward section of the first end of the beam and the head disposed forward of the pivot point can have a forward weight. Meanwhile, a rearward section of the second end of the beam and the end weight disposed rearward of the pivot point can have a rearward weight, where the forward weight is balanced relative to the rearward weight about the pivot point.

[0029] The crank point can be situated vertically rearward below the first bearing point on the beam when the beam is situated horizontally. In this instance, the first bearing point can be disposed at a first horizontal dimension (C) along the beam relative to the fulcrum point, and the crank point can be disposed at a second horizontal dimension (I) relative to the fulcrum point, where the second horizontal dimension (I) can be greater than the first horizontal dimension (C).

[0030] This other arrangement of the pumping unit can include any of the additional features described above with reference to the previous arrangement.

[0031] According to yet another arrangement of the present disclosure, a reciprocating pump system is used for a well. The system comprises a downhole pump disposed in the well and comprises a pumping unit disposed at the surface and coupled to the downhole pump by a rod string. The pumping unit can include any of the various features of the pumping units described above.

[0032] The foregoing summary is not intended to summarize each potential embodiment or every aspect of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] FIG. **1** illustrates an example of a reciprocating rod pump system known in the art.

[0034] FIG. **2**A illustrates an elevational view of a reciprocating rod pump system of the present disclosure.

[0035] FIG. **2**B illustrates geometry of the disclosed reciprocating rod pump system.

[0036] FIG. **3**A illustrates an elevational view of another reciprocating rod pump system of the present disclosure.

[0037] FIG. **3**B illustrates geometry of the disclosed reciprocating rod pump system.

[0038] FIG. **3**C illustrates another geometry of the disclosed reciprocating rod pump system.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0039] Referring to FIG. **2**A, a surface pumping unit **100** according to the present disclosure is used for reciprocating a rod string for a downhole pump in a well. Details of the well, wellhead, polished rod, carrier bar, downhole pump, and the like are not shown here for simplicity, but have been discussed previously.

[0040] The pumping unit **100** includes a frame having a base **110** and a Samson post **112**. An actuator or prime mover **120** is disposed on the base **110**, a crank assembly is connected to the prime mover **120**, and a walking beam **150** is connected to the crank assembly and is supported by the Samson posts **112** on the base **110**. Structurally, the Samson posts **112** on the base **110** provide a fulcrum point on which the walking beam **150** is pivotally supported by a saddle bearing assembly **116**. In addition to the Samson posts **112**, the frame on the base **110** may include one or more back posts **114** joined together forming an A-frame to support the walking beam **150**.

[0041] The pumping unit **100** is driven by the prime mover **120**, such as an electric motor or internal combustion engine, mounted on a pedestal above the base **110**. A pump controller (not shown) monitors, controls, and records the pump unit's operation. Output from the prime mover **120** is transmitted to a gearbox **124**, which provides low-speed, high-torque rotation of a crankshaft **132**. Both ends of the crankshaft **132** rotate a respective crank arm **130** about the crankshaft's centerline. Disposed away from the crankshaft **132**, the crank arms **132** each have a counterbalance weight **136**. Each crank arm **130** is pivotally connected to a pitman arm **140** by a crank pin bearing **134**, also called a wrist pin. In turn, the two pitman arms **140** are connected to an equalizer bar **142**, which is pivotally connected toward the rear end **151***b* of the walking beam **150** by an equalizer bearing assembly **156**.

[0042] A horsehead **152** with an arcuate forward face **154** is mounted to the forward end **151***a* of the walking beam **150**. As is typical, the face **154** may have runners (tracks or grooves) for carrying a flexible wire rope bridle **56**. At its lower end, the bridle **56** terminates with a carrier bar (not shown), upon which a polished rod (not shown) for a reciprocating rod system is suspended. As before, the polished rod typically extends through a packing gland or stuffing box at a wellhead for connection to downhole sucker rods and pump.

[0043] As the prime mover **120** rotates the crank arms **130**, the walking beam **150** seesaws on the frame's bearing **116** so the polished rod reciprocates the rod system and downhole pump in the well. During operation, for example, the prime mover **120** and gearbox **124** rotate the crank arms **130**, which causes the rearward end **151***b* of the walking beam **150** to move up and down through the movement of the pitman arms **140**. Up and down movement of the rearward end **151***b* causes the walking beam **150** to pivot about the bearing assembly **116** resulting in downstrokes and upstrokes of the horsehead **152** on the forward end **151***a*.

[0044] During an upstroke, for example, the prime mover **120** and gearbox **124** aided by the counterbalance weights **136** overcomes the weight and load on the horsehead **152** and pulls the polished rod string up from the wellbore, which reciprocates the rod string and downhole pump in the well to lift fluid. During a downstroke, the prime mover **120** aided by the weight and load on the horsehead **154** rotates the crank arms **130** to raise the counterbalance weights **136**.

[0045] The pumping unit **100** may be used for specific pumping applications, calling for changes in its particular geometry and structure compared to a conventional unit. The unit **100** may also be used in pumping applications having particular requirements for rod loads, stroke length, and the like. For example, the unit **100** may have an oversized horsehead **152**, an increased forward length (A) on the beam **150**, or other changes to produce longer strokes with the unit **100**.

[0046] The changes in the geometry and the structure, the changes in the particular rod loads, or the like can produce imbalance in the unit **100**. To offset the imbalance, the unit **100** according to the present disclosure has an end weight **160** on the rearward end **151***b* of the beam **150**. The end weight **160** can include a unitary or modular unit and can have a fixed weight value. The end weight **160** can attach or affix to the end **151***b* in a number of ways. For example, the end weight **160** can be attached to the rearward end of the beam **150** using techniques, such as welding, bolting, flanges, and the like. The attachment may be permanent or may allow for different end weights **160** with different weight values to be used interchangeably as needed on the end **151** of the beam **150**.

[0047] The end weight **160** is configured to eliminate the imbalance of the beam **150** and the head **152** and allow the gear reducer **124** and the crank arm counterweights **136** to only have to lift the rod string. This configuration may allow the pumping unit **100** to pull higher loads than a conventional unit. Moreover, this configuration may allow for easier set-up of the unit **100** due to the zero-imbalance of the beam **150**. For example, the beam **150** with head **152** and weight **160** can easily be adjusted with little force (inertia) during set up on the frame (**112**, **114**), which may eliminate the need for heavier installation equipment. The reduced inertia may also reduce the amount of torque needed from the prime mover **120** to initiate motion and/or to sustain the desired motion that lifts and lowers the rod string.

[0048] Although the configuration can be incorporated into any size of the unit **100**, the benefits may be best suited for the pumping unit **100** when head heavy, as is typically found in a larger stroke unit. Some installations require pumping units having larger or longer strokes compared to conventional arrangements. The typical stroke length of a conventional pumping unit may be from about 50-in to about 240-in, whereas the stroke length for a larger stroke, conventional pumping unit installation may be from about 150-in to 300-in. (Reference to larger stroke here is not meant to be confused with those "long stroke pumping units" that use a belt drive.)

[0049] For the larger stroke pumping units, the length of the walking beam ahead of the fulcrum point **116** has to be increased so as to provide the larger stroke. This results in a longer arm dimension "A" for the distance from the center of the saddle bearing **116** to the centerline of the polished rod. In general, the arm dimension (A) from the fulcrum point **116** to the face **154** of the head **152** is greater than the other beam dimension (C) from the fulcrum point **116** to the equalizer bearing point **156**. For the larger stroke pumping unit **100** disclosed here, the forward dimension (A) can be about two times longer than the rearward dimension (C), but other variations can be used. In general, the ratio of the forward dimension (A) relative to the rearward dimension (C) can be between approximately 0.8 to just over 2 (e.g., about 2.05). In addition to the additional arm length, the longer stroke unit also requires a longer runner for the wire rope bridle so that the head **152** must be larger, which results in more weight. The longer moment arm (A) and head weight create a large structural imbalance in the beam **150**.

[0050] In the unit **100** having a longer moment arm (A) and an oversized horsehead **152** and/or having a significant increase in the imbalance due to other secondary effects, additional counterweight **136** could be added to the crank arms **130** to offset the imbalance. Increasing the counterweight **136** on the crank arms **130** would add to the rotational inertia effects, which may not be desirable. Instead, the present arrangement adds the additional weight to the rearward end **151***b* of the beam **150** using the end weight **160**. This added weight **160** to the end **151***b* of the beam **150** changes the articulating inertia effects, which may have benefits in some implementations.

[0051] In many installations, for example, the prime mover **120** is driven with a variable speed drive. This tends to keep the rotational speed of the gear reducer **124** and the crank arms **130** at nearly a constant rate. Therefore, any rotational inertia effects are reduced considerably and may be of concern only during start-up and shut-down operations. However, if such a unit were allowed to operate in an out-of-balance condition, the rotational inertia effects can become more pronounced. The end weight **160** on the end **151***b* of the beam **150** opposite the horsehead **152** to overcome the imbalance will tend to increase the articulating inertia. However, the beam **150** is supported on (and rotates about) the saddle bearing assembly **116**, which may tend to reduce the net effect.

[0052] In particular, even though the articulating inertia is increased, the requirement to overcome the imbalance with the counterweights affixed to the crank arms is reduced. In turn, the net torque required from the prime mover to operate the unit **100** is reduced. Essentially, the added weight to the end of the walking beam to offset the imbalance increases the articulating inertia slightly and reduces the rotational inertia. More significantly, the amount of counterweight torque required is reduced. Example calculations show that the additional weight **160** on the end of the walking beam **150** may reduce the counterweight torque on the order of about 30%, which is a big savings when it comes to motor power requirements. Additionally, the example calculations show that the net inertia effects of the articulating members do not increase enough to raise any other concerns.

[0053] Additional features of the pumping unit **100** are discussed with reference to FIG. **2**B, which schematically depicts the geometric arrangement of the unit **100**. In this depiction, the frame, actuator, arms, and the like are not shown. Instead, the fulcrum point for the walking beam **150** is represented as a pivot point for the bearing assembly **116**.

[0054] As shown in the geometry of FIG. **2**B, the rearward end **151***b* of the beam **150** has the bearing point (i.e., equalizer bearing assembly **156**) and has the additional end weight **160** disposed rearward of the bearing point **156**. Because the beam **150** is pivotable at the fulcrum point of the saddle bearing assembly **116** on the frame, a forward section **153***a* of the forward end of the beam **150** and the head **152** disposed forward of the pivot point **116** has a forward weight (WF+WH), whereas a rearward section **153***b* of the rearward end of the beam **150** and the end weight **160** disposed rearward of the pivot point **116** has a rearward weight (WR+WE).

[0055] For the disclosed pumping unit **100**, the forward weight (WF+WH) is intended to be balanced relative to the rearward weight (WF+WE) about the fulcrum point **116**. Accordingly, the weight value (WE) for the end weight **160** is selected to achieve this balance by countering any increased weight from an increased length (A) of the forward beam end and from an increased size for the head **152** so the pumping unit **150** can be used for longer stroke applications.

[0056] In one implementation, for example, the walking beam **150** has a weight (WF+WR) of about 6,500-lbs, and the head **152** has a weight (WH) of about 3500-lbs. The equalizer beam **142** can be about 1,300-lbs. For this implementation, the weight value (WE) for the end weight **160** can be about 6,500-lbs. In this instance, the extra weight value (WE) provided by the end weight **160** can be about ⅓ of the total weight of the assembly (walking beam **150**, head **152**, equalizer beam **142**, and end weight **160**). Of course, as one skilled in the art will appreciate with the benefit of the present disclosure, the weight value (WE) for the end weight **160** will vary depending on the lengths (A) and (C) of the beam **150** and other variables, dimensions, and weights of elements on the pumping unit **100**.

[0057] The face **154** connects to the polished rod extending along the wellbore axis WA from the wellhead. The prime mover (**120**) is not shown, but the crank arm (**130**) is depicted as radius (R) connected between a crank point of the crank pin **132** and a first bearing point for the wrist pin **134**. The pitman arm (**140**) is depicted as linkage (P) connected between the first bearing point **134** and a second bearing point for the equalizer bearing assembly **152** on the walking beam **150**.

[0058] The crank point **132** is disposed at a first dimension (K) relative to the fulcrum point **116** (i.e., the distance from the centerline of the crankshaft to the center of the saddle bearing), and the pitman arm (**130**) has a length of a second dimension (P) (i.e., the effective length of the pitman arm (**130**) as measured from the center of the equalizer bearing **156** to the center of the crank pin bearing **134**). The first bearing point **134** is disposed at a third dimension (R) from the crank point **132** (i.e., the distance from the centerline **132** of the crankshaft to the center of the crank pin bearing **134**), and the second bearing point **156** is disposed at a fourth dimension (C) relative to the fulcrum point **116** (i.e., the distance from the center of the saddle bearing **116** to the center of the equalizer bearing **156**). This completes the four-bar linkage of the unit **100**.

[0059] Other geometric measures include the dimension (A), heights (H) and (G), and separation (I). The dimension (A) is the distance from the center of the saddle bearing **116** to the centerline of the polished rod represented by the wellbore axis WA and defines the radius at which the face **154** arcs along (circumscribes) a segment at a radius relative to the fulcrum point **116**, the segment being tangential to the wellbore axis (WA). The height (H) is the fixed elevation of the fulcrum point **116** from the surface S on which the base (**110**) is supported, and the height (G) is the fixed elevation of the crank point **134** from the surface S. Finally, the separation (I) is the fixed vertical distance between the fulcrum point **116** and the crank point **132**.

[0060] As noted, the unit **100** operates as a kinematic four-bar linkage (KPRC), in which each of four rigid links (KPRC) is pivotally connected to two other of the four links (KPRC) to form a closed polygon. In the mechanism, the link (K) is fixed as the ground link. The two links (C, R) connected to the ground link (K) are referred to as grounded links, and the remaining link (P) not directly connected to the fixed ground link (K) is referred to as the coupler link. The grounded link (R) rotated by the prime mover about the crank point **132** translates the coupler link (P) arm to oscillate the grounded link (C) for the beam **150** on the fulcrum point **116**. This in turn oscillates the radius (A) at which the face **154** arcs along (circumscribes) the segment.

[0061] Configuring the four-bar linkage (KPRC) of the unit **100** may configure the operating characteristics of the pumping unit **100**, such as defining the allowable polished rod load, defining the shape of the permissible load envelope, defining the length of the pumping stroke, inducing a phase angle shift in the counterbalance, etc. Moreover, the configured operating characteristics at surface may further defines controls, analysis, and diagnostics of the downhole rod pump because calculations for these features are typically based on the four-bar linkage (K-R-P-C).

[0062] Arranged for longer stroke applications, the unit **100** may have a forward beam dimension (A) that is increased compared to a standard stroke pumping unit. The head **152** may also be larger, having an increase weight (WH) and having a face **154** that may define a greater segment compared to a standard stroke pumping unit. However, the end weight **160** on the rearward end **151***b* of the beam **150** that produces the zero-imbalance of the beam **150** can allow the unit **100** to operate efficiently as a kinematic four-bar linkage (KPRC) using many of the same or similar components (i.e., prime mover **120**, gearbox **124**, crank arms **130**, counterweights **136**, pitman arms **140**, and the like) as used for a conventional longer stroke pumping unit. This provides the unit **100** with flexibility to meet the needs of various pumping implementations.

[0063] In the present arrangement of FIGS. **2**A-**2**B, the gear reducer **124** operably connecting the prime mover **120** to the crankshaft **132** is situated in a conventional manner. In particular, the gear reducer **124** has a slow-speed shaft—i.e., the crankshaft **132** about which the crank arms **130** rotate. For this conventionally situated reducer, the center of this slow-speed crankshaft **132** is situated relative to the unit's fulcrum point **116** so that the crankshaft **132** may sit directly under the center of the equalizer bearing **156**. Accordingly, in the arrangement of FIGS. **2**A-**2**B, the crank point of the crankshaft **134**, which is the slow-moving shaft of the reducer **124**, can be centered vertically below the rearward bearing point (i.e., equalizer bearing **156**) on the beam **150** when the beam **150** is situated horizontally. In other words, the horizontal distance (I) between the saddle bearing **116** and the crank point **132** may the same as or approximately close to the horizontal distance (C) between the saddle bearing **116** and the equalizing bearing **156**.

[0064] The values of these horizontal distances (I) and (C) depend on the particulars of the implementation, such as the other dimensions (e.g., KPRAGH) of the unit **100**, rod loads, counterweight values, etc. In general, the horizontal distances (I) and (C) can be approximately equal with the difference being approximately between 0 to 10%. In fact, the horizontal distances (I) can be equal to about the distance from the fulcrum point **116** to the end **151***b* of the beam **150**, which is typically about 9% greater than the distance (C). Such an arrangement dictates some of the other dimensions for the interconnected links (KPRC) of the unit **100**.

[0065] Additionally, the cranks' bearing point or wrist pin **134** on the crank arm **130** is disposed on the arm's longitudinal axis **131**, as seen in FIG. **2**B. In particular, the crankpin holes in the pumping unit **100** run parallel to the longitudinal axis **131** of the crank arm **130**. Therefore, the counterweights **136** on the crank arms **130** do not lag relative to the pivot connection (wrist pins **134**) between the crank arms **130** and the pitman arms **140** as the crank arms **130** rotate clockwise. The pumping unit **100** could run either clockwise or counterclockwise.

[0066] The arrangement of the various elements of the disclosed unit **100** is preferably configured so that the pitman arms (**140**) operate in tension. The counterbalance weight **136** is selected based on the weight and load of the reciprocating rod system (i.e., the force required to lift the reciprocating rod and fluid above the downhole pump in the wellbore). In one embodiment, the counterbalance weight **136** may be selected so that one or more components of the pumping unit **100** have substantially symmetrical acceleration and/or velocity during upstrokes and downstrokes. The component may be any moving part of the pumping unit **100**, such as the pitman arm **140**, the wrist pin assembly **134**, the crank arm **130**, the equalizer beam **142**, the walking beam **150**, the horsehead **152**, etc.

[0067] Turning to FIG. **3**A, another arrangement of a pumping unit **100** is illustrated. Many features of this pumping unit **100** are similar to those discussed previously. Again, the surface pumping unit **100** is operated by a prime mover **120** for reciprocating a rod load for a downhole pump in a well. The unit **100** includes a frame **112**, **114**, a beam **150**, a crank arm **130**, a counterweight **136**, and a pitman arm **140**. The frame **112**, **114** is disposed at the surface and has a fulcrum point **116**, about which the beam **150** is pivotable at a pivot point. A forward end **151***a* of the beam **150** has a head **152** connecting to the rod load extending from the well. The second or rearward end **151***b* has a first bearing point **156** and has an end weight **160** disposed rearward of the first bearing point **156**.

[0068] The crank arms **130** are connected to the prime mover **120** and are rotatable thereby about a crank point **132**. The counterweights **136** are disposed on the crank arms **130**. The pitman arms **140** are connected between the first bearing point **156** on the beam **150** and second bearing points or wrist pins **134** on the crank arm **130**. The second bearing points **134** are disposed on the crank arm **130** between the counterweights **136** and the crank points **132**.

[0069] The unit **100** includes these and other features similar to those disclosed previously with reference to FIG. **2**A. In addition to having the zero-imbalance beam **150** with the end weight **150**, the present configuration is a phased pumping unit where the crank arms **130** are designed with the counterweights **136** lagging behind the attachment point (i.e., wrist pins **134**) of the pitman arms **140**.

[0070] A geometric arrangement of the unit **100** is schematically depicted in FIG. **3**B. As with the previous arrangement of FIG. **2**B, a forward section **153***a* of the forward end of the beam **150** and the head **152** disposed forward of the pivot point **116** has a forward weight (WF+WH), whereas a rearward section **153***b* of the rearward end of the beam **159** and the end weight **160** disposed rearward of the pivot point **116** has a rearward weight (WR+WE). The forward weight (WF+WH) can be balanced relative to the rearward weight (WF+WE) about the pivot point **116** so that the benefits of the previous arrangement can be achieved. Accordingly, the weight value (WE) for end weight **160** is selected to achieve this balance by countering any increased weight from an increased length (A) of the forward beam end and from an increased size for the head **152** so the pumping unit **150** can be used for longer stroke applications.

[0071] In contrast to the previous arrangement, the second bearing points or wrist pins **134** are disposed offset at an angle (α) from the longitudinal axes **131** of the crank arms **130**. In particular, the crankpin holes in a conventional pumping unit run parallel to the longitudinal axis **131** of the crank arm **130**. For this phased unit **100**, however, the crankpin holes for the wrist pin **134** are placed at an offset angle (α) from the longitudinal axis **131** of the crank arm **130**. (The value of the offset angle (α) depends on the particulars of the implementation, such as the dimensions (e.g., KPRCAGHI) of the unit **100**, rod loads, counterweight values, etc. In general, the offset angle (α) can be about 5-deg., but could be between 4-deg. and 15-deg. in most implementations.) Therefore, the counterweights **136** on the crank arms **130** lag behind the pivot connection (wrist pins **134**) between the crank arms **130** and the pitman arms **140** as the crank arms **130** rotate clockwise. The phased pumping unit **100** must rotate clockwise. The length (P+) of the pitman arm **140** may be different than the previous arrangement due to the lagging counterweight (**136**).

[0072] Another geometric arrangement of the unit **100** is schematically depicted in FIG. **3**C. This arrangement is similar to those discussed above with reference to FIGS. **2**B and **3**B. Again, a forward section **153***a* of the forward end of the beam **150** and the head **152** disposed forward of the pivot point **116** has a forward weight (WF+WH), whereas a rearward section **153***b* of the rearward end of the beam **159** and the end weight **160** disposed rearward of the pivot point **116** has a rearward weight (WR+WE). The forward weight (WF+WH) can be balanced relative to the rearward weight (WF+WE) about the pivot point **116** so that the benefits of the previous arrangement can be achieved. Accordingly, the weight value (WE) for the end weight **160** is selected to achieve this balance by countering any increased weight from an increased length (A) of the forward beam end and from an increased size for the head **152** so the pumping unit **150** can be used for longer stroke applications.

[0073] In addition to having the zero-imbalance beam **150** with the end weight **160**, the present configuration is a phased pumping unit where the crank arms **130** are designed with the counterweights **136** lagging behind the attachment points (i.e., wrist pins **134**) of the pitman arms **140**. For example, similar to the previous arrangements, the second bearing point or wrist pin **134** is disposed offset at an angle (α) from a longitudinal axis **131** of the crank arm **130**. In particular, the crankpin holes for this phased unit **100** are placed at an offset angle (α) from the longitudinal axis **131** of the crank arm **130**. Therefore, the counterweights **136** on the crank arms **130** lag behind the pivot connection (wrist pins **134**) between the crank arms **130** and the pitman arms **140** as the crank arms **140** rotate clockwise. (Again, the offset angle (α) can be about 5-deg. or between 4-deg. and 15-deg. in most implementations.) The phased pumping unit **100** must rotate clockwise. The length (P+) of the pitman arm **140** may be different than the previous arrangement due to the lagging counterweight (**136**).

[0074] In contrast to the previous arrangements, the gear reducer **124** for this unit **100** in FIG. **3**B is placed further back from the walking beam pivot point (i.e., saddle bearing assembly **116**). In other words, the crank point of the crankshaft **132** is situated vertically rearward below the bearing point **156** on the beam **150** when the beam **150** is situated horizontally. In particular and as noted previously, the gear reducer **124** has a slow-speed shaft—i.e., the crankshaft **132** about which the crank arms **130** rotate. For a conventionally situated reducer, the center of this slow-speed crankshaft would be situated relative to the unit's fulcrum point so that the crankshaft may sit directly under the center of the equalizer bearing shaft. In this phased pumping unit **100**, however, the gear reducer **124** is situated further back from the fulcrum point **116**. Therefore, the slow-speed crankshaft **132** of the gear reducer **124** on the phased unit **100** sits rearward of the equalizer bearing **156**. The horizontal separation (I+) of the crank point **132** from the fulcrum point **116** may be different than the previous arrangement. In other words, the horizontal distance (I+) between the saddle bearing **116** and the crank point **132** is greater than the horizontal distance (C) between the saddle bearing **116** and the equalizing bearing **156**. Again, the values of these horizontal distances (I+) and (C) depend on the particulars of the implementation, such as the other dimensions (e.g., KPRAGH) of the unit **100**, rod loads, counterweight values, etc. In general, the horizontal distance (I+) can be greater in length than the beam's horizontal distance (C). In other words, the horizontal distance (I+) can be greater than approximately 10%) in length than the beam's horizontal distance (C). Such an arrangement dictates some of the other dimensions for the interconnected links (KPRC) of the unit **100**.

[0075] As the geometries of Figs. Although not explicitly shown, the feature of the gear reducer **124** situated further back from the fulcrum point **116** (as in FIG. **3**B) could be used with crankpin holes that are aligned along the longitudinal axis **131** of the crank arm **130** (as in FIG. **2**B).

[0076] The foregoing description of preferred and other embodiments is not intended to limit or restrict the scope or applicability of the inventive concepts conceived of by the Applicants. It will be appreciated with the benefit of the present disclosure that features described above in accordance with any embodiment or aspect of the disclosed subject matter can be utilized, either alone or in combination, with any other described feature, in any other embodiment or aspect of the disclosed subject matter.

[0077] In exchange for disclosing the inventive concepts contained herein, the Applicants desire all patent rights afforded by the appended claims. Therefore, it is intended that the appended claims include all modifications and alterations to the full extent that they come within the scope of the following claims or the equivalents thereof.

What is claimed is:

1. A surface pumping unit operated by a prime mover for reciprocating a rod load for a downhole pump in a well, the unit comprising:

a frame disposed at surface and having a fulcrum point;

a beam being pivotable at the fulcrum point of the frame, the beam having first and second ends, the first end having a head connecting to the rod load extending from the well, the second end having a first bearing point and having an end weight disposed rearward of the first bearing point, a forward section of the first end of the beam and the head disposed forward of the fulcrum point having a forward weight, a rearward section of the second end of the beam and the end weight disposed rearward of the fulcrum point having a rearward weight, the forward weight being balanced relative to the rearward weight;

a crank arm connected to the prime mover and rotatable thereby about a crank point;

a counterweight disposed on the crankarm; and

a pitman arm connected between the first bearing point on the beam and a second bearing point on the crank arm, the second bearing point being disposed between the counterweight and the crank point.

2. The unit of claim **1**, wherein the crank arm rotated by the prime mover about the crank point translates the pitman arm to oscillate the beam on the fulcrum point and reciprocates the rod load along the wellbore axis.

3. The unit of claim **1**, wherein the frame comprises:

a base disposed at the surface; and

a post extending from the base to the fulcrum point along a line from vertical.

4. The unit of claim **1**, wherein the beam defines a straight axis having first and second sections, the first section from the fulcrum point to a face of the head having a first length (A), the second section from the fulcrum point to the first bearing point having a second length (C);

and wherein the first length (A) is greater than the second length (C).

5. The unit of claim **1**, wherein the fulcrum point comprises a saddle bearing; wherein the first bearing point comprises an equalizer bearing; and wherein the second bearing point comprises a crank pin bearing.

6. The unit of claim **1**, further comprising:

another crank arm connected to the prime mover and rotatable thereby about another crank point; and

another pitman arm connected between another first bearing point on the beam and another second bearing point on the other crank arm,

wherein the pitman arms connect with an equalizer beam at the first bearing point.

7. The unit of claim **1**, further comprising a gear reducer operably connecting the crank point to the prime mover.

8. The unit of claim **1**, wherein the crank point is centered vertically below the first bearing point on the beam when the beam is situated horizontally.

9. The unit of claim **8**, wherein the first bearing point is disposed at a first horizontal dimension (C) along the beam relative to the fulcrum point; and wherein the crank point is disposed at a second horizontal dimension (I) relative to the fulcrum point, the second horizontal dimension (I) being approximately equal to the first horizontal dimension (C).

10. The unit of claim **8**, wherein the crank arm defines a longitudinal axis, the second bearing point being disposed along the longitudinal axis of the crank arm.

11. The unit of claim **8**, wherein the crank arm defines a longitudinal axis, the second bearing point being disposed offset at an angle from the longitudinal axis of the crank arm.

12. The unit of claim **1**, wherein the crank point is situated vertically rearward below the first bearing point on the beam when the beam is situated horizontally.

13. The unit of claim **12**, wherein the first bearing point is disposed at a first horizontal dimension (C) along the beam relative to the fulcrum point; and wherein the crank point is disposed at a second horizontal dimension (I) relative to the fulcrum point, the second horizontal dimension (I) being greater than the first horizontal dimension (C).

14. The unit of claim **12**, wherein the crank arm defines a longitudinal axis, the second bearing point being disposed along the longitudinal axis of the crank arm.

15. The unit of claim **12**, wherein the crank arm defines a longitudinal axis, the second bearing point being disposed offset at an angle from the longitudinal axis of the crank arm.

16. A surface pumping unit operated by a prime mover for reciprocating a rod load for a downhole pump in a well, the unit comprising:

a frame disposed at the surface and having a fulcrum point;

a beam being pivotable at the fulcrum point of the frame, the beam having first and second ends, the first end having a head connecting to the rod load extending from the well, the second end having a first bearing point and having an end weight disposed rearward of the first bearing point;

a crank arm defining a longitudinal axis, the crank arm connected to the prime mover and rotatable thereby about a crank point;

a counterweight disposed on the crankarm; and

a pitman arm connected between the first bearing point on the beam and a second bearing point on the crank arm, the second bearing point being disposed between the counterweight and the crank point and being disposed offset at an angle from the longitudinal axis of the crank arm.

17. The unit of claim **16**, wherein a forward section of the first end of the beam and the head disposed forward of the pivot point having a forward weight, a rearward section of the second end of the beam and the end weight disposed rearward of the pivot point having a rearward weight, the forward weight being balanced relative to the rearward weight about the pivot point.

18. The unit of claim **16**, wherein the crank point is situated vertically rearward below the first bearing point on the beam when the beam is situated horizontally.

19. The unit of claim **18**, wherein the first bearing point is disposed at a first horizontal dimension (C) along the beam relative to the fulcrum point; and wherein the crank point is disposed at a second horizontal dimension (I) relative to the fulcrum point, the second horizontal dimension (I) being greater than the first horizontal dimension (C).

20. A reciprocating pump system for a well, the system comprising:

a downhole pump disposed in the well; and

a pumping unit according to claim **1** or claim **16** disposed at the surface and coupled to the downhole pump by a rod string.

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